PB-216 192

STUDY REPORT ON A PILOT-PLANT CONICAL INCINERATOR

William C. Achinger

Bureau of Solid Waste Management
Cincinnati, Ohio

1970

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 216 192

STUDY REPORT ON A PILOT-PLANT CONICAL INCINERATOR

This report (SW-14ts) was written by
William C. Achinger

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
Bureau of Solid Waste Management
1970

61

FOREWORD

Incineration is an important method of solid waste processing in the United States, and although over 300 incinerators are in operation, little information on the performance of these units is available. It is therefore not surprising that the effects of incineration on the environment are little understood and frequently ignored.

An incinerator discharges effluents into the environment in three states: solid, liquid, and gaseous. The sources of these effluents are the processes of combustion, gas cleaning, and residue quenching. Any determination of the pollution contribution to the environment by incineration must be concerned with all these effluents.

The Bureau of Solid Waste Management, through the Division of Technical Operations, has initiated a testing program to characterize the performance of incinerators of different designs and configurations. The primary objectives of this program are to produce basic information that identifies the results of the incineration process and to develop reliable sampling methodology.

During the studies it is considered necessary to make a complete analysis of all features that affect the operation of the facility

as well as those that influence its potential for environmental pollution. The operation of the facility is not altered in any way unless specific study objectives dictate a change. Therefore, no special effort is made to operate the facility at its design capacity; rather, it is tested at its "operating" capacity.

Reports from each study in this program will be prepared primarily for use by the management of the facility, although they will be available upon request to other interested technical personnel. Each report will contain only the data obtained during one individual study. Data comparisons with other studies will not be made in individual study reports. Summaries and comparisons of the data from all studies will be reported annually. Persons interested in receiving these annual reports should contact the Office of Information, Bureau of Solid Waste Management, 5555 Ridge Avenue, Cincinnati, Ohio 45213.

--RICHARD D. VAUGHAN, *Director*
Bureau of Solid Waste Management

CONTENTS

INTRODUCTION 1

SUMMARY 3

FACILITY DESCRIPTION AND OPERATION 5

STUDY PROCEDURES 13

Solid Waste 13

Residue 16

Fly Ash 17

Stack Effluents 18

Wastewater 21

Bacteriological Samples 22

RESULTS AND DISCUSSION 23

Particulate Emissions 23

Air Pollution Control Equipment Efficiencies 26

Test Results 30

REFERENCES 39

ACKNOWLEDGMENTS 40

APPENDICES 41

A Example Calculations for Solid Waste Proximate Analysis Results 43

B Example Calculations for Residue Proximate Analysis Results 46

C Calculation of Air Pollution Control Equipment Efficiencies 50

D Calculation of Combustion Efficiency 51

TABLES

1 Summary of Stack Tests 24

2 Particulate Emissions to the Atmosphere 25

3 Solid Waste Composition 27

4 Efficiency of Particulate Air Pollution Control Equipment 29

5 Charging Rates 31

6 Proximate Analysis of Solid Waste 31

7 Quantity of Residue 32

8 Residue Composition 32

9 Proximate Analysis of Residue 33

10 Proximate Analysis of Fly Ash 33

11 Wastewater Solids Concentration 35

12 Wastewater Chemical Characteristics 36

13 Solid Waste Bacteriological Data 37

14 Residue Bacteriological Data 37

15 Wastewater Total Bacterial Count 38

16 Combustion Efficiency 38

A-1 Laboratory Data: Solid Waste Proximate Analysis . . . 43

A-2 Calculation of Percent of Dry Component: Solid Wastes 44

B-1 Laboratory Data: Residue Proximate Analysis 47

B-2 Calculation of Percent of Dry Component: Residue 48

D-1 Calculation of Dry Component Weight 52

D-2 Calculation of Daily Particulate Emissions 53

D-3 Calculation of Weight of Dry Volatiles 55

D-4 Calculation of Total Heat Content 56

FIGURES

1 Plan View of Conical Incinerator 6

2 Underfire Air System 7

3 Water Scrubber and Afterburner Ductwork 9

4 Electrostatic Precipitator Ductwork 12

5 Flow of Materials Into and Out of Incinerator and Location of Sampling Points 14

STUDY REPORT ON A PILOT-PLANT CONICAL INCINERATOR

There is considerable interest in the conical incinerator as a means of solid waste volume reduction because of the low capital cost of the conical incinerator as compared to the capital expenditures required to construct a refractory-lined incinerator of equal capacity. However, pollution abatement officials are concerned about the impact such an incinerator would have on the environment, particularly the air resource.

Aware of these concerns, the Burn-O-Matic Division, Steelcraft Corp.,* Memphis, Tennessee, has constructed a pilot-plant conical incinerator for purposes of research and development. The pilot plant was equipped with an afterburner and a water scrubber to control the air pollution emissions. A request was made to the Bureau of Solid Waste Management to evaluate the performance of this pilot unit.

As a result of this request, a study was conducted from July 29 to August 2, 1968, to determine whether the conical incinerator can process solid wastes efficiently without adversely affecting the environment. In a further attempt to control air pollution, an electrostatic precipitator was installed on the incinerator for this study only.

---

*Mention of a company or commercial product does not imply endorsement by the U.S. Public Health Service.

REPORT SUMMARY

The incinerator tested, a pilot plant designed to process 1,000 lb of solid waste per hr, incorporated upper and lower duct sprays, a water scrubber, an afterburner, and, for this study only, an electrostatic precipitator. These air pollution control devices could be operated independently or, to a degree, in series. During this study, the incinerator operated with the water scrubber alone, with the afterburner and water scrubber in series, and with the electrostatic precipitator alone.

Approximately 13 tons of waste were processed through the conical burner at a rate of 1,430 lb/hr. The waste as sampled comprised paper products (30.2%), food waste (20.3%), ash, rocks, and dirt (11.1%), garden waste (11.1%), glass and ceramics (10.5%), and other components (less than 10% each). The heat content of the solid waste was 8,790 Btu/lb and its moisture content was 26.5 percent.

After incineration, the total residue as sampled was approximately 6,800 lb with a heat content of 180 Btu/lb. The residue contained 1 3 percent unburned combustibles and, on a dry basis, 2.0 percent volatiles. Weight reduction efficiency was approximately 62 percent, reduction in volatiles was approximately 99 percent, and

Preceding page blank

reduction in heat content was approximately 99 percent. Incineration reduced the total bacterial count from 6.8×10^8/g of waste to 1.2×10^6/g of residue; heat resistant spores from 1.9×10^6 to 1.1×10^5; total coliform from 5.1×10^7 to 18; and fecal coliform from 8.2×10^6 to 11.

With the scrubber and lower duct spray operating, 18 gpm of process water were used; with the scrubber and upper duct spray operating, 23 gpm were used; and with the lower duct spray operating, 4 gpm were used. The resultant wastewaters were acidic (2.6 pH). The average conductivity was 907 µmhos/cm. On an average they contained solids (637 mg/liter; 150 mg/liter were suspended solids), no detectable alkalinity, chlorides (256 mg/liter), hardness (107 mg/liter), sulfates (77 mg/liter), and phosphates (5.0 mg/liter).

The fly ash collected in the electrostatic precipitator had a heat content of 3,400 Btu/lb as sampled and contained 52.4 percent moisture.

The gas-borne particulate emissions, expressed in gr/scf of dry flue gas corrected to 12 percent CO_2, were 0.56 with the water scrubber operating, 0.41 with the afterburner and scrubber operating, and 0.30 with the electrostatic precipitator operating.

The scrubber and the electrostatic precipitator collected respectively, 70.6 and 84.0 percent of the gas-borne particulates.

FACILITY DESCRIPTION AND OPERATION

The incinerator is a model C-20, double-walled, conical burner equipped with air pollution control devices and designed to process 1,000 lb/hr of solid waste. The Burn-O-Matic Division of the Steelcraft Corp. operates the facility (Figure 1) as a pilot plant for research and development purposes.

The combustion chamber is a 23-ft-high truncated cone with a 20-ft-diameter base. The combustion chamber wall consists of two 16-gauge steel shells--a tightly sealed inner shell and an outer shell for structural support that is open to the atmosphere at the base. The space between the two shells permits air to circulate freely around the inner shell and augments heat transfer from the combustion chamber.

A forced-draft underfire air system (Figure 2) and an induced-draft system provide combustion and cooling air to the combustion chamber. Ambient air is drawn in between the inner and outer shells of the combustion chamber, through an opening atop the inner shell, and into a rectangular duct mounted inside the inner shell. The air passes through this duct to the base of the combustion chamber and through a second duct out of the chamber to the primary air fan. This fan, capable of delivering 2,800 cfm at 4 in. of water, static

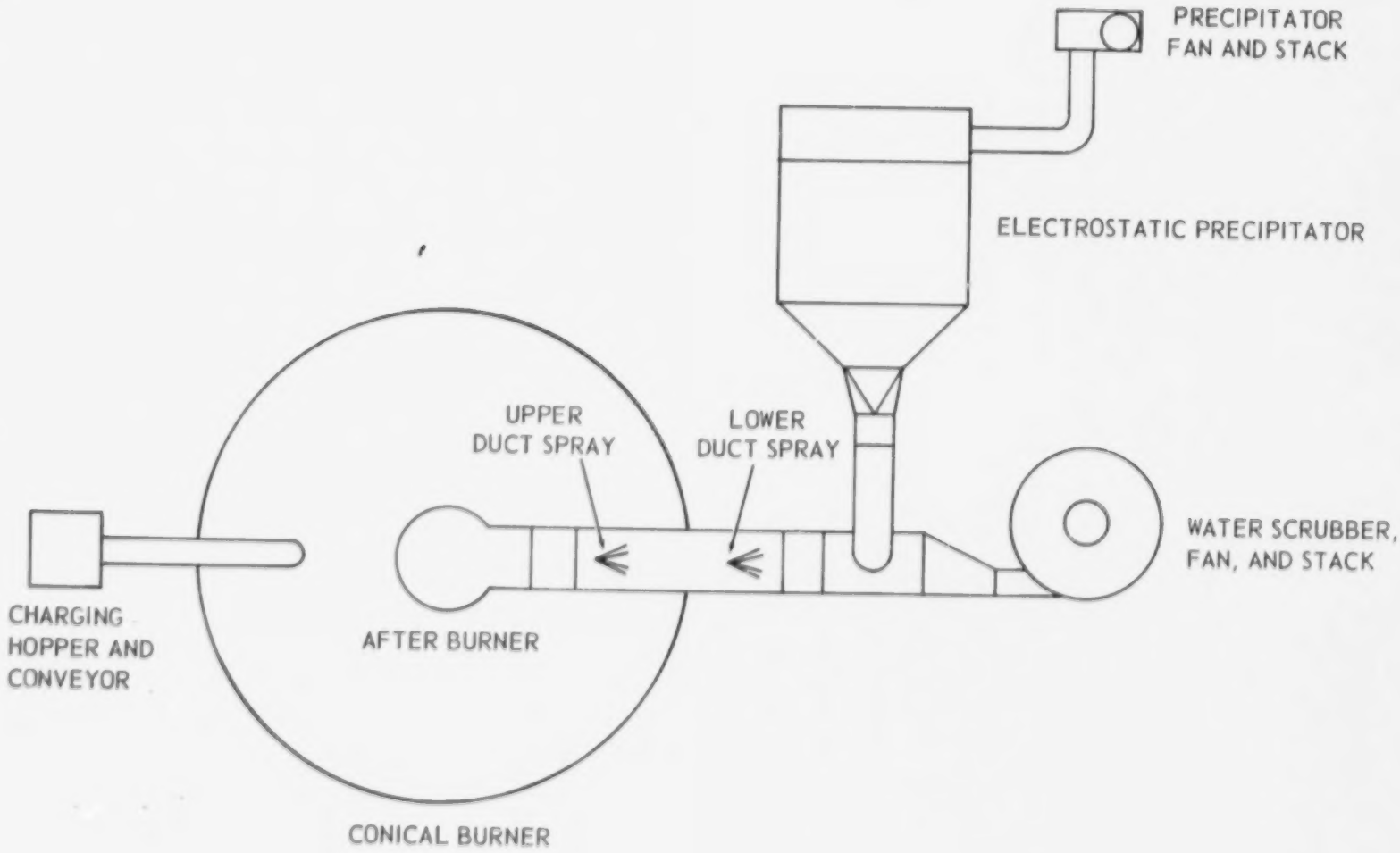

Figure 1. Plan view of conical incinerator.

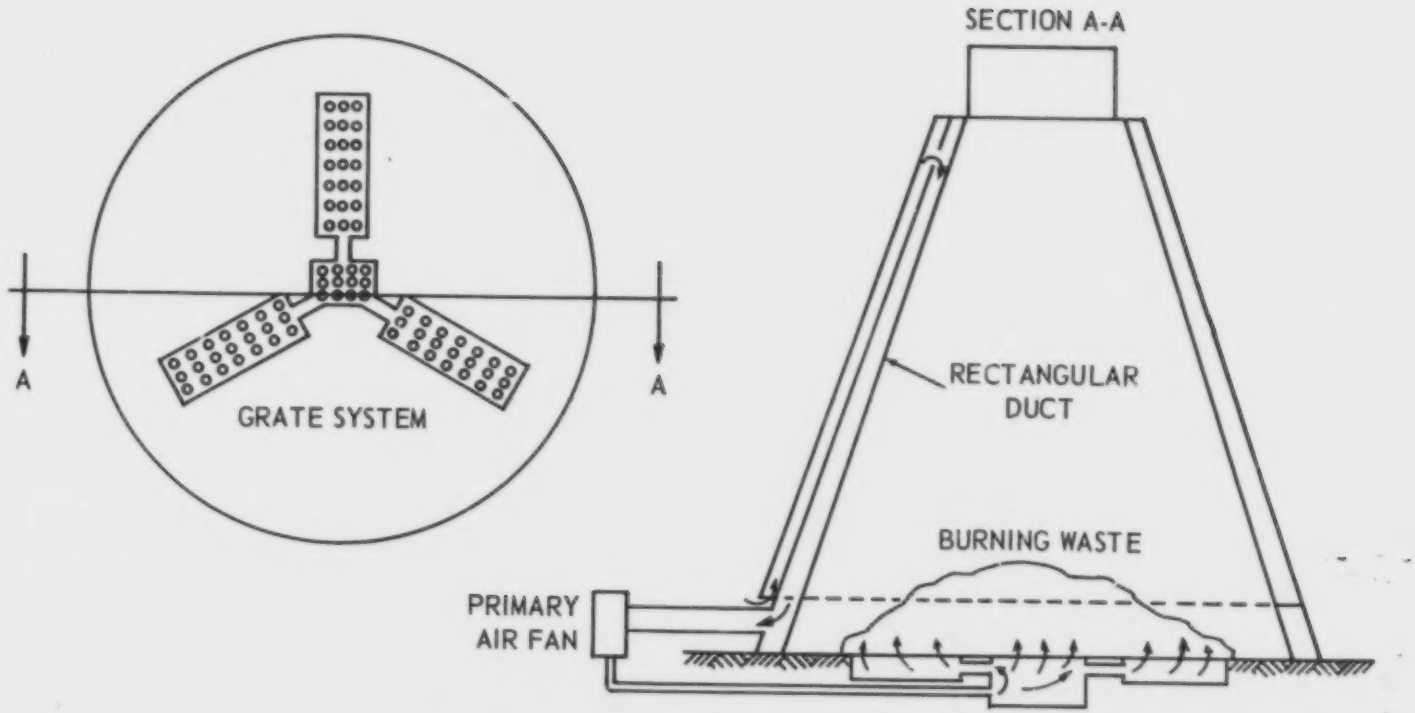

Figure 2. Underfire air system.

pressure (actual flow during tests was less than 1,000 cfm, because of throttling), forces the air to a distribution box in the floor of the combustion chamber. This box distributes the air to three fixed perforated steel grates, where it passes up through the pile of burning waste. As the underfire air passes up between the combustion chamber walls and down through the rectangular duct, it picks up heat until it reaches approximately 220 F.

The combustion gases pass through a cap on the combustion chamber, down a duct on the exterior of the unit, and then to the air pollution control systems (Figure 3). The induced draft is provided by the air pollution control equipment fans (Figure 1). A 3,600-cfm (12 in. water, static pressure) fan incorporated into the scrubber provides the draft when the water scrubber is operating. A 5,000-cfm (2 in. water, static pressure) fan located after the precipitator provides the draft when the electrostatic precipitator is operating.

Overfire air enters the combustion chamber by air infiltration through seven 5-in.-diameter pipes extending through the chamber wall at its base. Flow through the seven overfire air pipes is regulated by sliding plate dampers, although they were not adjusted during the tests. Total flow through the pipes during the tests was less than 100 cfm. Overfire air also enters the combustion chamber by means of air infiltration through leaks in the combustion walls. This flow was not measured during the tests.

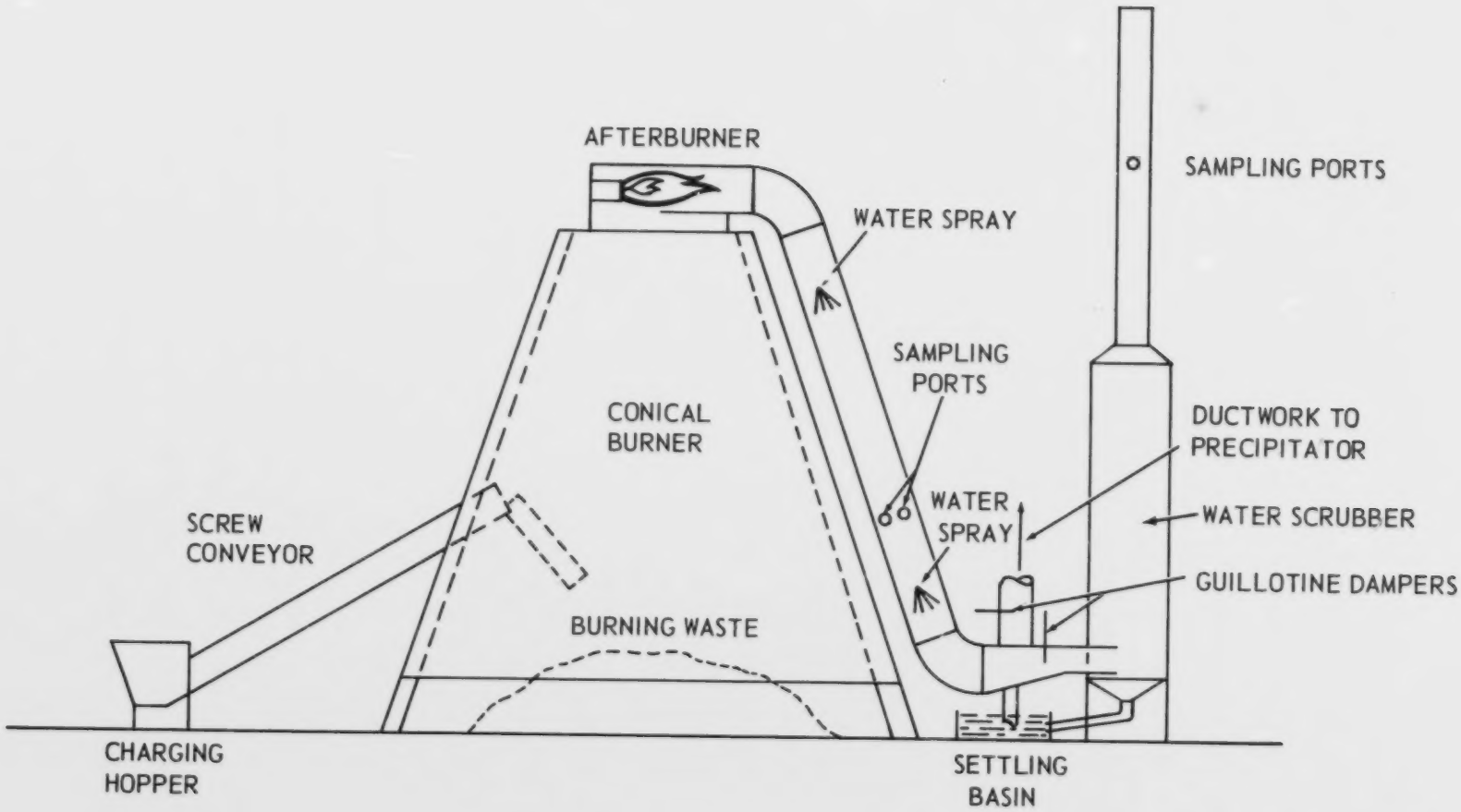

Figure 3. Water scrubber and afterburner ductwork.

The waste-charging system is a hopper (approximately 1 cu yd in capacity) and a screw conveyor that transports the waste to the combustion chamber, where it enters at about one-third the chamber height and drops down a chute onto the pile of burning waste (Figure 3). Incoming waste is manually charged into the incinerator through the hopper-screw conveyor system. Frequently during the tests the screw conveyor jammed, and charging had to be halted (about 1 min) until the conveyor was cleared. The unit is designed to be charged for 10 to 12 hr per day. At the end of a day's charging, the material remaining in the unit is allowed to burn down. The underfire air system is kept on during burndown.

During the tests, the unit was operated to maintain a prescribed exit-gas temperature measured at the entrance to the air pollution control equipment duct system. Both the quantity of waste charged and the underfire air-flow rate were adjusted to maintain this temperature.

Each morning, before the day's burning began, the cool residue from the previous day was manually removed with a shovel and hauled to a landfill.

To control fly ash emissions to the atmosphere, the incinerator is equipped with an afterburner, upper and lower duct sprays, a water scrubber, and an electrostatic precipitator (Figure 1). Three control system combinations were tested: lower duct spray and water scrubber; afterburner, upper duct spray, and water scrubber; and lower duct spray and electrostatic precipitator.

The afterburner, located above the combustion chamber (Figure 3) is a natural-gas-fired unit designed to provide 2 million Btu/hr. It was designed and constructed especially for this application and is not available commercially.

Although the duct sprays function primarily to cool the effluent gases and the duct work, they provide a degree of fly ash control because of the abrupt change in direction the gases undergo at the bottom of the duct work. Both spray systems provide a coarse water spray. Water flow through the upper and lower duct spray systems was approximately 9 gpm and 4 gpm, respectively.

The water scrubber is a 36-in. Ducon Dynamic Gas Scrubber, Type UW-4. Water flow through the scrubber was approximately 14 gpm. Figure 3 shows the duct arrangement for this system.

A Research Cottrell electrostatic precipitator, designed to treat 10,000 cfm of dust-laden flue gases, was installed for this study (Figure 4). The unit is constructed of twelve 7-ft, 6-in.-high ducts spaced 6 in. apart. Gases flow horizontally through the unit with a treatment length of 7 ft 2 in. The inlet duct contains a perforated flow distribution plate. Power requirements are 220-v, single-phase, 60-Hertz current. The power supply is a 50-kv peak voltage at 75 ma with a 20-amp maximum demand on the primary winding.

Wastewater from the duct spray drain and the water scrubber is treated in a settling basin before being discharged into a drainage ditch.

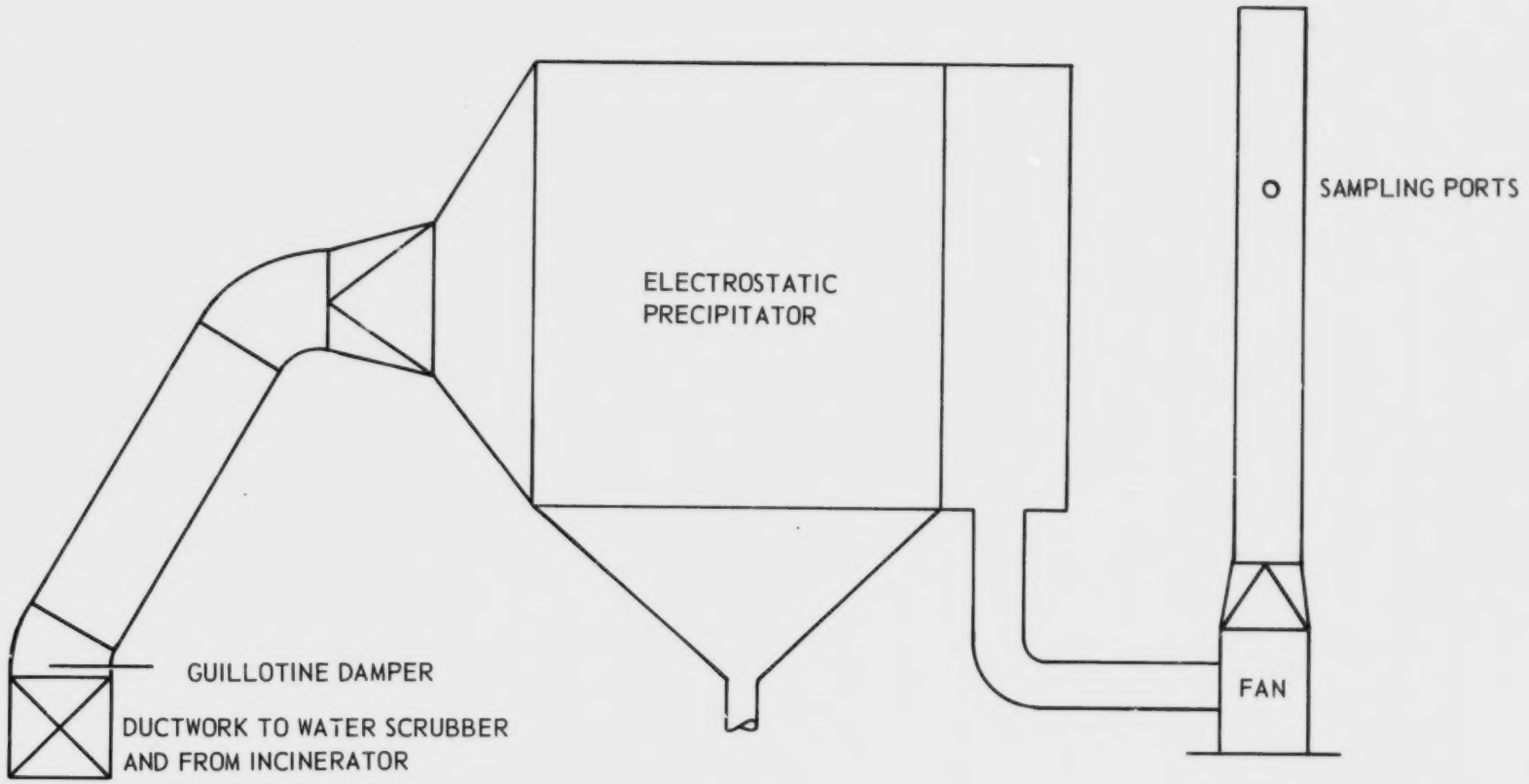

Figure 4. Electrostatic precipitator ductwork.

STUDY PROCEDURES

This section discusses the methods used to collect and analyze the following samples: solid waste, residue, fly ash, stack particulate emissions, stack gases, and process water. Figure 5 shows a flow diagram of the solid, liquid, and gaseous materials into and out of the incinerator and the sampling locations used during the study.

Solid Waste

All solid waste used during the study was obtained from the city of Memphis. The waste, collected from residential routes, was transferred from the collection vehicle to trailers so that the weight of waste used during the study could be determined.

Seven 200- to 350-lb samples of the solid wastes were collected during the study: one on the first day of the study and two on each of the next 3 days (one in the morning and one in the afternoon). The waste samples were obtained directly from the waste trailers, using a wheelbarrow and pitchfork, then dumped onto a large plastic sheet and manually separated into the following categories:

Combustibles:

- Food waste
- Paper products
- Plastic, rubber, and leather
- Wood
- Garden waste
- Textiles

Noncombustibles:

- Metals
- Glass and ceramics
- Ash, rocks, and dirt

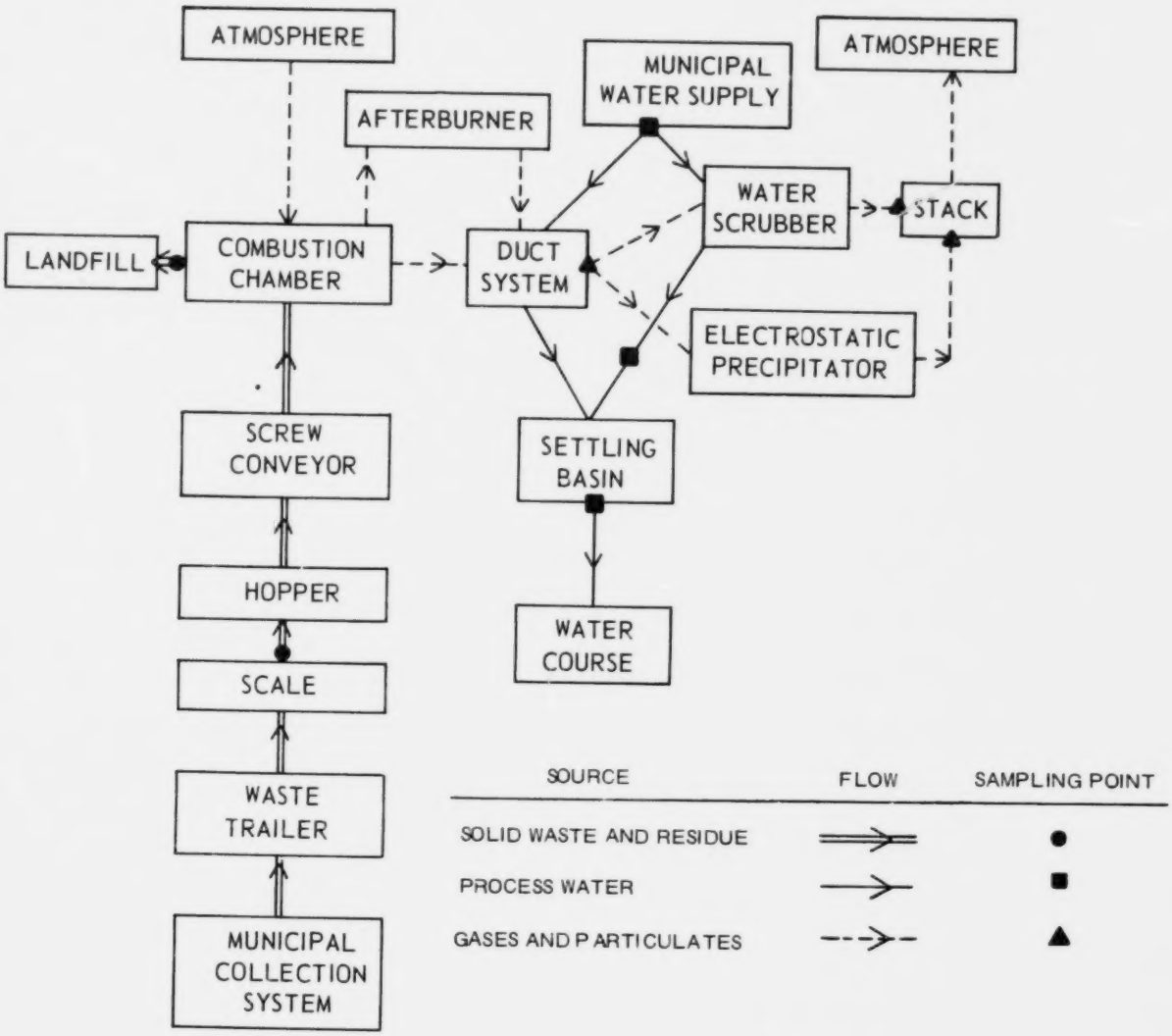

Figure 5. Flow of materials into and out of incinerator and location of sampling points.

The weight of material in each category was determined and the total sample weight and percent by weight of material in each category computed.

Also, 10- to 15-lb laboratory samples were prepared from four of the samples taken to determine waste composition. A proportionate amount of material by weight from each of the combustible categories was placed in two plastic bags, one inside the other, and each bag was knotted separately to prevent moisture loss. Noncombustibles (metals, glass and ceramics, and ash, dirt, and rocks) were not included.

The laboratory samples were analyzed for moisture content, heat content, and volatile* and ash contents.

These samples were prepared for analysis by processing them through a hammermill and reducing them to about 1 in. maximum dimension. This ground product was spread on a plastic sheet, thoroughly mixed manually, and quartered, with alternate quarters being discarded. This quartering and discarding process was repeated until 3- to 4-lb samples were obtained.

To determine moisture content, several 100-g (approximate) portions of each sample were dried in a mechanical convection oven at 70 C to constant weight. The moisture content was then calculated.

The dried samples were prepared for subsequent analyses by being ground in a Wiley mill until they passed through a 2-mm mesh sieve.

---

*Material determined by laboratory analysis.

The heat content of the dried samples was determined in a Parr adiabatic calorimeter, using the method prescribed in the Parr Instrument Company's Manual No. 130.[1]

The volatile and ash contents of the dried samples were determined in accordance with the American Public Works Association's procedures outlined in "Tentative Methods of Analysis of Refuse and Compost."[2]

Residue

Because residue is removed manually with shovels in this facility, samples for a given day's tests had to be taken the following morning, after the combustion chamber cooled.

To determine the quantity of residue from a day's operation, all the residue was removed from the incinerator and weighed.

To obtain samples of the residue, a path (one shovel wide) was shoveled through a representative area (determined by visual inspection) from the edge to the center of the pile. The residue samples were placed in a 55-gal drum and weighed to determine total sample weight.

The sample was then dumped on a large canvas sheet and manually separated into four categories: metals; glass, ceramics, rocks, bricks, etc.; unburned combustibles;* and fines (unidentifiable material passing a 1/2-in. wire mesh screen). After separation,

*Material that can be visually identified as being from one of the six categories of combustible materials used to define the composition of incoming waste, such as charred paper, wood, orange peels, etc.

the weight of material in each category was determined and the percent by weight in each category computed.

The unburned portion of combustible materials in the residue sample was stored in a small plastic bag knotted at the top. The fines, together with the bagged unburned combustibles, were placed in another larger plastic bag also knotted at the top. To prevent moisture loss, this bag was placed inside another bag and sealed in a similar manner.

The laboratory samples were analyzed for moisture content, heat content, and volatile and ash contents.

The unburned combustibles from each residue sample were prepared for analysis in a manner identical to that used for the solid waste samples. The fines from each residue sample, however, were only ground in an Iler pulverizer.

The moisture content, heat content, and volatile and ash contents were determined in the same manner as for the solid waste samples.

Fly Ash

A fly ash sample was taken when the water scrubber was operating by collecting a sample of the sludge in the bottom of the settling basin. Another fly ash sample was collected when the electrostatic precipitator was operating by collecting the fly ash from the hopper in a plastic bag.

To determine the volatile and ash contents, the fly ash sample from the scrubber settling basin was analyzed according to the procedures outlined in "Standard Methods for the Examination of Water and Waste Water."[3] The fly ash sample from the electrostatic precipitator was ground in an Iler pulverize· and then analyzed for moisture content, heat content, and volatile and ash contents by the same procedures used to analyze the solid waste samples.

Stack Effluents

A series of nine tests was run during the week to determine the operating efficiencies of the various air pollution control devices installed on this unit. Three stack-emission tests were conducted on each of the following collector combinations: lower duct spray and water scrubber; afterburner, upper duct spray, and water scrubber; lower duct spray and electrostatic precipitator. In addition to outlet measurements, measurements were made at the inlet to the collectors. However, when the upper duct spray was operating, it was impossible to collect samples at the inlet to the collectors. Inlet and outlet tests were run simultaneously.

Particulates. The sampling methods and the equipment used to determine the particulate emissions in this study are based on those prescribed in "Specifications for Incinerator Testing at Federal Facilities."[4]

Samples were taken at the inlet to the fly ash control systems, using a 6-point traverse, sampling two paraliel rows of three points

each in the 20-in.-sq duct. The sampling ports were located 5 duct widths downstream and 2 duct widths upstream from any bend in the duct work. Velocity data did not indicate a wide variation in flow across the cross section (velocity pressure head varied from 0.16- to 0.31-in. H_2O). Samples were taken using a 3/8-in. nozzle. Except for the first test, which required 10 min, sampling time at each point was 6 min. (Plugging of the sampling filter required the sampling time to be reduced after the first test.)

Samples were taken at the scrubber outlet, using a 12-point traverse sampling on two perpendicular diameters in a 14-3/4 in. round stack. The sampling ports were located 7 stack diameters downstream from the scrubber outlet and 7 stack diameters upstream from the exit point to the atmosphere. Velocity data did not indicate a wide variation in flow across the cross section (velocity pressure head varied from 0.65- to 1.25-in. H_2O without the afterburner operating and from 0.73- to 1.5-in. H_2O with the afterburner operating). Samples were taken using a 3/16-in. nozzle. Sampling time at each point was 5 min.

Samples were taken at the precipitator outlet, using a 12-point traverse sampling on two perpendicular diameters in an 18-in. round stack. The sampling ports were located 8 stack diameters downstream from the precipitator fan outlet and 2-2/3 stack diameters upstream from the exit point to the atmosphere. Velocity data indicated a uniform flow pattern across the cross section (velocity pressure head varied from 1.10- to 1.40-in. H_2O). Samples were taken using a 3/16-in. nozzle. Sampling time at each point was 5 min.

The particulate samples were analyzed according to the procedures prescribed in "Specifications for Incinerator Testing at Federal Facilities."[4]

Stack Gas Composition. To determine the composition of dry stack gases, integrated gas samples were collected in a flexible Tedlar bag during each stack test, transferred to a flexible Tedlar transfer bag, and transported to another area at the facility for analysis. The samples were collected at approximately 0.8 liter/min; the total volume collected was approximately 40 liters. The samples were analyzed for carbon dioxide, carbon monoxide, and oxygen, using a Burrell Gas Analysis Apparatus (Orsat) Model No. 39-505. The remainder was assumed to be nitrogen.

During each stack test, a series of grab samples were taken to determine the carbon dioxide concentration in the stack gases. These samples were collected and analyzed in a Dwyer Model 1101 CO_2 Indicator..

The moisture content of the stack gases was measured simultaneously with each particulate sample extraction. To dry the gas stream passing through the particulate sampling train, it was sent through three Greenburg-Smith impingers immersed in an ice bath and then through another Greenburg-Smith impinger filled with silica gel to remove any remaining water vapor. The temperature of the gases leaving the final impinger was approximately 70 to 80 F. The increase in volume of liquid (assumed to be water) in the impingers was determined by measuring the initial and final volumes in a 500-ml graduated cylinder. The initial and final weights of the silica gel were measured and

weight gain was attributed to water adsorption. These quantities of water were used to calculate the moisture content of the stack gases.

Wastewater

All liquid samples were collected and analyzed according to the procedures outlined in "Standard Methods for the Examination of Water and Waste Water,"[3] with the exception of the analysis for phosphates.[5]

Two grab samples from the water scrubber drain (when the scrubber was operating), the water settling basin, and the water overflow from the electrostatic precipitator hopper (when the precipitator was operating) were collected during each stack test. A composite sample was made from equal portions of the grab samples collected during a given stack test and analyzed for biochemical oxygen demand (BOD). Another composite sample for each source was made for each day by combining equal portions of the composite samples taken for BOD analysis. This daily composite sample was analyzed for chemical oxygen demand (COD). A third composite sample was made for the determination of the solids and chemical characteristics of the wastewaters from each source. This last sample was a daily composite made in the same manner as the composite sample for COD analysis.

Bacteriological Samples

Bacteriological samples were taken of the solid waste, residue, fly ash emissions, and the wastewater. All samples were collected aseptically. The samples were analyzed for total bacterial count, total and fecal coliforms (using the Most Probable Number Technique), and total heat-resistant spores using analytical procedures outlined in "Standard Methods for the Examination of Water and Waste Water."[3]

RESULTS AND DISCUSSION

Particulate Emissions

Because the outlet concentration of particulates during stack test No. 1 appeared to be unreasonable when compared with the other tests at the "same" operating conditions, it was omitted when calculating average emissions and collector efficiencies (see Table 1).

In the sampling train used in this study, particulates are collected in the probe and cyclone, on the filter, and in the first three impingers. A major portion of the total particulates collected while sampling the effluent gases from the electrostatic precipitator was trapped in the distilled water used in the impingers. In test No. 7, this amounted to 64 percent of the total particulates; in test No. 8, 35 percent; and in test No. 9, 60 percent. Thus, 35 to 64 percent of the particulate emissions from the electrostatic precipitator (Tables 1 and 2) are materials that were trapped in the impingers. The origin of these materials was questioned because, if they are considered particulate emissions, the incinerator with an electrostatic precipitator will not meet the Federal code for incinerators located at Federal facilities. If they are not considered particulate emissions, the incinerator will meet this standard. The samples from this study were discarded before the question arose, so

TABLE 1

SUMMARY OF STACK TESTS

Control equipment and test run	Time (min)	Average CO_2 content in stack gases (%)	Excess air (%)	Particulate emissions			
				gr/scf at 12% CO_2	lb/1,000 lb at 50% E.A.	lb/hr	lb/ton waste
Lower duct spray and scrubber:							
Test 1 (inlet)	50	4.6	330	1.01	2.08	8.65	10.54
Test 1 (outlet)	60	3.3	400	0.88	1.53	5.95	7.26
Test 2 (inlet)	36	3.3	500	1.37	2.89	8.70	10.61
Test 2 (outlet)	60	2.6	400	0.55	0.75	2.78	3.39
Test 3 (inlet)	27	5.2	240	1.33	2.45	13.26	18.16
Test 3 (outlet)	60	3.1	310	0.56	0.75	3.56	4.88
Upper duct spray, afterburner, and scrubber:							
Test 4 (outlet)	60	2.9	220	0.41	0.40	2.01	2.75
Test 5 (outlet)	60	4.5	250	0.37	0.61	3.02	4.13
Test 6 (outlet)	60	2.6	190	0.46	0.37	2.32	3.18
Lower duct spray and electrostatic precipitator:							
Test 7 (inlet)	24	3.1	380	5.69	8.94	32.44	54.52
Test 7 (outlet)	60	3.1	380	0.30	0.47	1.70	5.24
Test 8 (inlet)	24	3.4	440	2.88	5.94	17.46	29.34
Test 8 (outlet)	60	3.3	430	0.37	0.68	2.16	6.00
Test 9 (inlet)	24	4.3	410	0.58	1.34	4.41	7.42
Test 9 (outlet)	60	3.5	410	0.22	0.40	1.34	4.42

TABLE 2

PARTICULATE EMISSIONS TO THE ATMOSPHERE

Control equipment and test run	Particulate emissions							
	gr/scf*			lb/1,000 lb dry flue gas				
	At existing CO_2	At 12% CO_2	At 50% E.A.	At existing CO_2	At 12% CO_2	At 50% E.A.	lb/hr	lb/ton waste
Lower duct spray and scrubber (average of test 2 and 3)	0.14	0.56	0.40	0.25	1.06	0.75	3.17	4.14
Upper duct spray, afterburner, and scrubber (average of tests 4, 5, and 6)	0.11	0.41	0.23	0.21	0.78	0.46	2.45	3.35
Lower duct spray and electrostatic precipitator (average of tests 7, 8, and 9)	0.08	0.30	0.24	0.15	0.55	0.52	1.73	2.92

*Standard conditions are 70 F; 29.92 in. Hg, and dry.

analysis of the samples was impossible. In a subsequent study, however, the residue left after evaporation of the distilled water was analyzed for metals. This analysis indicated that approximately 20 percent of the material were metals, and considering that these metals are in the oxide form, the percentage of weight owing to metal oxides would be even higher. The remaining materials in the residue have not yet been identified, but they are probably inorganic salts. As such, it is felt that these materials should be considered as particulates.

From Table 1, it can be seen that the inlet loading to the electrostatic precipitator collector system decreased appreciably during the course of the day's tests. This is probably because the composition of the waste being incinerated during the day changed. In the morning, the waste contained 32.2 percent ash, rocks, and dirt, whereas in the afternoon this category had decreased to 13.9 percent (Table 3). It is felt that much of the ash, rocks, and dirt was entrained in the combustion gases as the waste being charged fell from the charging point to the burning waste pile, resulting in the changing inlet loading as the quantity of these materials changed.

Air Pollution Control Equipment Efficiencies

Many measurements for ascertaining such things as carbon dioxide, carbon monoxide, oxygen, and nitrogen concentrations in the flue gases, waste charging rate, and the particulate emission rate are needed

TABLE 3

SOLID WASTE COMPOSITION

Component	Sample														Average percent
	7-29-68 pm*		7-30-68 am		7-30-68 pm*		7-31-68 am		7-31-68 pm*		8-1-68 am		8-1-68 pm*		
	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	
Combustibles:															
Food waste	38.5	18.7	70.2	30.0	55.2	20.0	62.7	26.8	51.2	20.3	44.0	12.9	39.2	13.5	20.3
Garden waste	0.0	0.0	0.0	0.0	31.3	11.4	5.0	2.1	65.5	26.0	58.7	17.2	61.8	21.2	11.1
Paper products	67.1	32.6	102.0	43.6	81.8	29.7	66.8	28.5	54.3	21.6	81.9	24.0	89.8	30.9	30.2
Plastic, rubber, leather	5.5	2.7	7.8	3.3	9.5	3.4	10.0	4.3	9.0	3.6	7.7	2.3	6.3	2.2	3.1
Textiles	14.5	7.0	7.5	3.2	22.2	8.1	31.3	13.4	4.5	1.8	3.0	0.9	4.8	1.6	5.2
Wood	1.8	0.9	2.8	1.2	3.2	1.1	3.8	1.6	7.3	2.9	1.4	0.4	11.3	3.9	1.7
Total	127.4	61.9	190.3	81.3	203.2	73.7	179.6	76.7	191.8	76.2	196.7	57.7	213.2	73.3	71.6
Noncombustibles:															
Metals	23.1	11.2	10.7	4.6	16.8	6.1	18.5	7.9	10.5	4.2	16.4	4.8	25.5	8.8	6.8
Glass and ceramics	50.6	24.6	31.0	13.3	35.2	12.8	18.2	7.9	14.5	5.8	18.2	5.3	11.5	4.0	10.5
Ash, rocks, dirt	4.7	2.3	2.0	0.8	20.4	7.4	17.7	7.5	34.7	13.8	109.6	32.2	40.5	13.9	11.1
Total	78 4	38.1	43.7	18.7	72.4	26.3	54.4	23.3	59.7	23.8	144.2	42.3	77.5	26.7	28.4
Grand total	205.8	100.0	234.0	100.0	275.6	100.0	234.0	100.0	251.5	100.0	340.9	100.0	290.7	100.0	100.0

*A proportionate amount of combustible fraction returned to laboratory for analyses.

to enable the efficiency of the air pollution control equipment to be determined. For a given test run, comparison of the reported air pollution collector efficiencies (Table 4) yields an indication of the precision of these measurements. Theoretically, the efficiencies should be the same regardless of the measurements and methods used to calculate them. However, because different measurements are used to calculate particulate concentrations expressed in different units, any error in the individual measurements will necessarily result in a different reported collector efficiency. Therefore, any deviation in collector efficiencies for a given test run is an indication of how well all the measurements were made.

Because the water in the scrubber absorbs carbon dioxide, the carbon dioxide content in the effluent gases is less than that entering the scrubber. In correcting the grain loading to 12 percent CO_2, the grain loading at existing CO_2 concentration and standard conditions is multiplied by the ratio of 12 over the existing carbon dioxide concentration, resulting in a higher adjusted outlet grain loading than would occur if all the carbon dioxide passed through the scrubber. Comparison of inlet and outlet carbon dioxide concentrations (Table 1) indicates that about one-third is removed by the scrubber. The efficiencies (Table 4) of this collector are, therefore, low when the efficiency calculation is based upon inlet and outlet grain loadings corrected to 12 percent CO_2. No adjustment for this reduction in carbon dioxide content is allowed when comparing emissions with the standard for incinerators at Federal facilities.

TABLE 4

EFFICIENCY OF PARTICULATE AIR POLLUTION CONTROL EQUIPMENT
(Percent)

Control equipment and test run*	Efficiency							
	Based on gr/scf†			Based on lb/1,000 lb flue gas			Based on lb/hr	Based on lb/ton
	At existing CO_2	At 12% CO_2	At 50% E.A.	At existing CO_2	At 12% CO_2	At 50% E.A.		
Lower duct spray and scrubber:								
Test 1	---	---	---	---	---	---	---	---
Test 2	68.4	59.9	73.7	68.1	59.8	74.0	68.1	68.1
Test 3	74.6	57.9	70.2	75.0	57.4	69.4	73.1	73.1
Average	71.5	58.9	72.0	71.6	58.6	71.7	70.6	70.6
Lower duct spray and electrostatic precipitator:								
Test 7	94.6	94.7	94.7	94.6	94.7	94.8	94.8	94.9
Test 8	87.8	87.2	87.6	87.6	87.3	87.8	87.6	87.7
Test 9	71.4	62.0	70.4	69.2	62.4	70.1	69.6	69.6
Average	84.6	81.3	84.2	83.8	81.5	84.2	84.0	84.1

*Collector efficiencies were not determined for test runs 4, 5, and 6 because an inlet sample could not be collected with the upper duct spray in operation.

†Standard conditions are 70 F, 29.92 in. Hg, and dry.

As can be seen from Table 4, the efficiency of the electrostatic precipitator decreases from test No. 7 (94.8%) to No. 9 (69.6%). No positive explanation can be given for this, but it may be owing to the changing inlet loading (Table 1), the changing composition of wastes being incinerated, or a decreasing collector efficiency as the plates become covered with fly ash.

Test Results

Approximately 13 tons of waste (Table 5) were processed through the conical incinerator at a rate of 1,430 lb/hr. The waste as sampled comprised paper products (30.2%), food waste (20.3%), ash, rocks, and dirt (11.1%), garden waste (11.1%), glass and ceramics (10.5%), and other components (less than 10% each) (Table 3). The heat content of the solid waste was 3,790 Btu/lb and its moisture content was 26.5 percent (Table 6).

TABLE 5

CHARGING RATES

Period charged	Amount of time charged		Total weight charged (lb)	Rate (lb charged/hr)
	min	hr		
July 30, 1968:				
9:30 am-11:45 am	135	2.25	---	---
12:50 pm-4:00 pm	190	3.16	---	---
Total	325	5.41	9,040	1,670
July 31, 1968:				
9:15 am-1:20 pm	245	4.08	---	---
2:45 pm-5:40 pm	175	2.92	---	---
Total	420	7.00	10,200	1,460
August 1, 1968:				
9:05 am-12:10 pm	185	3.08	---	---
1:10 pm-4:10 pm	180	3.00	---	---
Total	365	6.08	7,250	1,190
Grand total	1,110	18.49	26,490	1,430

TABLE 6

PROXIMATE ANALYSIS OF SOLID WASTE*

Date collected	Characteristic			
	As sampled		Dry basis	
	Moisture (%)	Heat (Btu/lb)	Volatiles (%)	Ash (%)
7-29-68	21.5	3,540	46.0	54.0
7-30-68	27.4	3,890	57.2	42.8
7-31-68	32.2	3,620	57.5	42.5
8-1-68	24.8	4,020	50.8	49.2
Average	26.5	3,790	52.9	47.1

*See Appendix A.

After incineration, the total residue as sampled was approximately 6,850 lb (Table 7). The residue contained 1.3 percent unburned combustibles (Table 8), and on a dry basis 2.0 percent volatiles, and a heat content of 180 Btu/lb (Table 9).

TABLE 7

QUANTITY OF RESIDUE

Date	Quantity (lb)
7-30-68	2,000
7-31-68	2,450
8-1-68	2,400
Total	6,850

TABLE 8

RESIDUE COMPOSITION

Component	7-30-68*		7-31-68*		8-1-68*		Average percent by weight
	Weight (lb)	Percent by weight	Weight (lb)	Percent by weight	Weight (lb)	Percent by weight	
Metals	16.3	20.1	5.5	7.1	10.5	11.7	13.0
Rocks, bricks, ceramics, and glass	38.3	47.2	46.5	60.0	29.9	33.4	46.8
Unburned combustibles	1.7	2.1	0.5	0.6	1.0	1.1	1.3
Fines	24.8	30.6	25.0	32.3	48.2	53.8	38.9
Total	81.1	100.0	77.5	100.0	89.6	100.0	100.0

*Samples were collected on following day.

TABLE 9

PROXIMATE ANALYSIS OF RESIDUE*

Date collected	Characteristic			
	As sampled		Dry basis	
	Moisture (%)	Heat (Btu/lb)	Volatiles (%)	Ash (%)
7-30-68	0.59	239	2.2	97.8
7-31-68	0.06	97	2.1	97.9
8- 1-68	0.38	217	1.7	98.3
Average	0.34	184	2.0	98.0

*See Appendix B.

The fly ash collected in the electrostatic precipitator had a heat content of 3,400 Btu/lb as sampled and contained 52.4 percent moisture (Table 10).

TABLE 10

PROXIMATE ANALYSIS OF FLY ASH

Source and date collected	Characteristic			
	As sampled		Dry basis	
	Moisture (%)	Heat (Btu/lb)	Volatiles (%)	Ash (%)
Scrubber (7-30-68)	---	---	16.4	83.6
Precipitator (8-1-68)	52.4	3,400	27.5	72.5

The gas-borne particulate emissions, expressed in gr/scf of dry flue gas corrected to 12 percent CO_2, were 0.56 with the water scrubber operating, 0.41 with the afterburner and scrubber operating, and 0.30 with the electrostatic precipitator operating (Table 2). A summary of individual stack test runs is presented in Table 1.

With the scrubber and lower duct spray operating, 18 gpm of process water were used; with the scrubber and upper duct spray operating, 23 gpm were used; and with the lower duct spray operating, 4 gpm were used. The resultant wastewaters on an average contained solids (637 mg/liter; 150 mg/liter were suspended solids), no detectable alkalinity, chlorides (256 mg/liter), hardness (107 mg/liter), sulfates (77 mg/liter), and phosphates (5.0 mg/liter). They were acidic (2.6 pH). The average conductivity was 907 μmhos/cm (Tables 11 and 12).

As shown in Tables 13 and 14, incineration reduced the total bacterial count from 6.8×10^8/g of waste to 1.2×10^6/g of residue; heat resistant spores from 1.9×10^6 to 1.1×10^5; total coliform from 5.1×10^7 to 18; and fecal coliform from 8.2×10^6 to 11. The total bacterial count in the wastewater is shown in Table 15.

The scrubber and the electrostatic precipitator collected respectively, 70.6 and 84.0 percent of the gas-borne particulates (as shown in Table 4).

Weight reduction efficiency was approximately 62 percent, reduction in volatiles was approximately 99 percent, and reduction in heat content was approximately 99 percent (Table 16).

TABLE II

WASTEWATER SOLIDS CONCENTRATION

Sample	Total solids					Suspended solids					Dissolved solids ($\frac{mg}{liter}$)
	Total ($\frac{mg}{liter}$)	Volatiles		Ash		Total ($\frac{mg}{liter}$)	Volatiles		Ash		
		$\frac{mg}{liter}$	%	$\frac{mg}{liter}$	%		$\frac{mg}{liter}$	%	$\frac{mg}{liter}$	%	
Test 2:											
Scrubber	648	354	54.6	294	45.4	107	52	48.6	55	51.4	541
Settling basin	620	315	50.8	305	49.2	123	68	55.3	55	44.7	497
Tests 3, 4, 5, and 6:											
Scrubber	542	275	50.7	267	49.3	92	34	41.5	58	58.5	450
Settling basin	655	317	48.4	338	51.6	178	90	50.6	88	49.4	477
Tests 7, 8, and 9:											
Precipitator drain	9,087	3,169	34.9	5,918	65.1	1,722	495	28.8	1,227	71.2	7,365
Settling basin	1,896	763	40.2	1,133	59.8	601	121	20.2	480	79.8	1,295

TABLE 12

WASTEWATER CHEMICAL CHARACTERISTICS

Sample	pH	BOD* (mg/liter)	COD† (mg/liter)	Alkalinity (g $CaCO_3$/liter)	Chloride (mg/liter)	Hardness (mg $CaCO_3$/liter)	Sulfate (mg SO_4/liter)	Phosphate (mg PO_4/liter)	Conductivity (umhos/cm)
Test 2:									
Scrubber	2.6	83	364	0	272	106	112.5	4.4	1,797
Settling basin	2.6	105	496	0	283	98	82.5	4.1	967
Tests 3, 4, 5, and 6:									
Scrubber	2.8	75	233	0	196	152	99.4	4.1	997
Settling basin	3.0	102	435	0	229	156	70.6	6.0	847
Tests 7, 8, and 9:									
Precipitator drain	3.6	235	1,620	0	3,201	1,888	462.5	53.5	5,997
Settling basin	3.2	86	305	0	466	398	101.2	23.8	1,597

*Biochemical oxygen demand.
†Chemical oxygen demand.

TABLE 13

BACTERIOLOGICAL DATA FOR SOLID WASTE

Sample	Total bacterial count (No./g)	Heat-resistant spores (No./g)	Total coliforms (mpn*/g)	Fecal coliforms (mpn*/g)
7-29-68	---	---	1.7×10^7	7.0×10^6
7-30-68	4.5×10^8	---	2.3×10^7	1.3×10^7
7-31-68	4.0×10^8	3.8×10^6	1.6×10^8	1.1×10^7
8- 1-68	1.2×10^9	1.3×10^3	3.5×10^6	1.7×10^6
Average	6.8×10^8	1.9×10^6	5.1×10^7	8.2×10^6

*Most probable number.

TABLE 14

BACTERIOLOGICAL DATA FOR RESIDUE

Sample	Total bacterial count (No./g)	Heat-resistant spores (No./g)	Total coliforms (mpn*/g)	Fecal coliforms (mpn*/g)
7-29-68	5.0×10^6	4.0×10^5	33	33
7-30-68	6.0×10^4	4.2×10^4	2	2
7-31-68	9.0×10^3	9.0×10^3	33	8
8- 1-68	3.0×10^3	3.0×10^2	2	2
Average	1.2×10^6	1.1×10^5	18	11

*Most probable number.

TABLE 15

TOTAL BACTERIAL COUNT OF WASTEWATER

Sample	Source	Count (No./ml)
7-29-68	Tapwater	0
7-30-68	Scrubber	1
7-31-68	Scrubber	15
8- 1-68	Precipitator drain	0

TABLE 16

COMBUSTION EFFICIENCY*

Type of efficiency	Percent efficiency
Dry weight reduction	62.5
Reduction in volatiles	98.6
Reduction in heat content	98.8

*See Appendix D.

REFERENCES

1. Parr Instrument Company. Operating the adiabatic calorimeter. In Oxygen bomb calorimetry and combustion methods. Technical Manual No. 130. Moline, Ill., 1960. p. 30-32.

2. American Public Works Association. Municipal refuse disposal. 2nd ed. Chicago, Public Administration Service, 1966. Appendix A. p. 375-399.

3. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Standard methods for the examination of water and wastewater; including bottom sediments and sludges. 12th ed. New York, American Public Health Association, Inc., 1965. 769 p.

4. National Center for Air Pollution Control. Specifications for incinerator testing at Federal facilities. Durham, N.C., U.S. Department of Health, Education, and Welfare, Oct. 1967. 35 p.

5. Gales, M. E., Jr., E. C. Julian, and R. C. Kroner. Method for quantitative determination of total phosphorus in water. Journal American Water Works Association, 58(10):1363-1368, Oct. 1966.

ACKNOWLEDGMENTS

The excellent assistance and cooperation extended by the staff of the Burn-O-Matic Division of the Steelcraft Corp. made the successful completion of this study possible. Special thanks are extended to David M. Franklin, whose efforts were essential in planning and conducting the study.

Special thanks are also extended to James H. Chaney, Director of the Division of Pollution Control, Memphis and Shelby County Health Department, and his staff for their assistance in analyzing the wastewater samples for BOD, COD, and pH.

Members of the field study team from the Bureau of Solid Waste Management were:

William C. Achinger	Tobias A. Hegdahl
David H. Armstrong	Donald A. King
James S. Bridges	John Klaas
Leland E. Daniels	Albert E. O'Connor
William T. Dehn	Ronald A. Perkins
John J. Giar	Jon R. Perry

Morris G. Tucker

Sample analyses were performed by the Division of Research and Development, Bureau of Solid Waste Management.

APPENDICES

APPENDIX A

Example Calculations For Results of Solid Waste Proximate Analysis

Based on the laboratory data from the proximate analysis of the combustible fraction of the solid waste sample and field separation data collected on July 29, 1968, these calculations show the methods used to calculate the moisture content, ash and volatile contents, and the heat content of the total sample. Table A-1 shows the laboratory data for the combustible fraction of the solid waste samples. The assumptions were made that the noncombustibles contained no moisture, no heat, and were considered as "ash." The field separation determined a combustible content for this sample of 61.9 percent on an as-sampled basis (Text Table 3).

TABLE A-1

LABORATORY DATA: SOLID WASTE PROXIMATE ANALYSIS

Date	Characteristic			
	As sampled		Dry basis	
	Moisture (%)	Heat (Btu/lb)	Volatiles (%)	Ash (%)
7-29-68	34.8	8,765	89.4	10.6
7-30-68	37.2	8,405	89.8	10.2
7-31-68	42.3	8,260	88.6	11.4
8- 1-68	33.9	8,298	78.8	21.2
Average	37.1	8,432	86.7	13.3

Preceding page blank

Moisture Content. Because the moisture in the total sample was assumed to be in the combustible portion only, the percent of moisture in the total sample is calculated by the following method:

$$\text{Percent moisture in total sample} = \left(\frac{\text{lb combustibles}}{\text{lb waste}}\right)\left(\frac{\text{lb moisture}}{\text{lb combustibles}}\right) 100$$

$$\text{Percent moisture in total sample} = (0.619)\ (0.348)\ (100) = 21.5$$

Volatile and Ash Contents. Because the volatile and ash fractions are determined in the laboratory on a dry basis, the percent of combustibles (Text Table 3) must be converted to a dry basis by the following method:

$$\text{Percent dry component} = \left(\frac{\text{weight of wet component minus the weight of water in component}}{\text{dry weight of total sample}}\right) 100$$

For example

$$\text{Percent dry combustibles} = \left(\frac{127.4 - 44.3}{161.5}\right) 100 = 51.5$$

These calculations are summarized in Table A-2.

TABLE A-2

CALCULATION OF PERCENT OF DRY COMPONENT: SOLID WASTES

Component	Component weight (wet) (lb)	Weight of moisture as sampled		Component weight (dry)	
		%	lb	lb	%
Combustibles	127.4	34.8	44.3	83.1	51.5
Noncombustibles	78.4	0.0	0.0	78.4	48.5
Total sample	205.8	21.5	44.3	161.5	100.0

The volatile content and ash content of the total sample are calculated as follows:

$$\text{Percent volatiles in total sample} = \left(\frac{\text{lb volatiles}}{\text{lb dry combustibles}}\right)\left(\frac{\text{lb dry combustibles}}{\text{lb waste}}\right) 100$$

$$\text{Percent volatiles in total sample} = (0.894)\ (0.515)\ (100) = 46.0$$

$$\text{Percent ash in total sample} = 100 \text{ minus the percent volatiles in total sample}$$

$$\text{Percent ash in total sample} = 100 - 46.0 = 54.0$$

Heat Content. The laboratory determined the heat content on a dry basis for the combustibles only. Therefore, the moisture content and noncombustibles present in the total sample must be accounted for when calculating the heat content of the total on an as-sampled basis. The heat content of the total sample is calculated as follows:

$$\text{Heat content of total sample} = \left(\frac{\text{Btu}}{\text{lb dry combustibles}}\right) \times \left[1 - \left(\frac{\text{percent moisture in total sample} + \text{percent noncombustibles in total sample}}{100}\right)\right]$$

$$\text{Heat content of total sample} = 8{,}765 \left[1 - \left(\frac{21.5 + 38.1}{100}\right)\right]$$

$$\text{Heat content of total sample} = 3{,}540 \text{ Btu/lb waste}$$

APPENDIX B

Example Calculations for Results of Residue Proximate Analysis

Using the laboratory data from the proximate analysis of the fines and unburned-combustible fractions of the residue sample and field separation data from July 30, 1968, these calculations show the methods used to calculate the moisture content, ash and volatile contents, and the heat content of the total sample. Table B-1 shows the laboratory data for the residue samples. The assumptions were made that the glass and rocks and metals contained no moisture, no heat, and were considered as "ash." The field separation determined the amount of unburned combustibles and fines to be 2.1 and 30.6 percent respectively on an as-sampled basis (Text Table 8).

Moisture Content. Because the moisture in the total sample was assumed to be in the unburned combustibles and fines, the percent of moisture in the total sample is calculated by the following method:

$$\text{Percent moisture in total sample} = \left[\left(\frac{\text{lb unburned combustibles}}{\text{lb residue}}\right)\left(\frac{\text{lb moisture}}{\text{lb unburned combustibles}}\right) + \left(\frac{\text{lb fines}}{\text{lb residue}}\right)\left(\frac{\text{lb moisture}}{\text{lb fines}}\right)\right] 100$$

$$\text{Percent moisture in total sample} = \left[(0.021)\ (0.115) + (0.306)\ (0.0115)\right] 100 = 0.59$$

TABLE B-1

LABORATORY DATA: RESIDUE PROXIMATE ANALYSIS

Date	Unburned combustibles				Fines			
	As sampled	Dry basis			As sampled	Dry basis		
	Moisture (%)	Heat (Btu/lb)	Volatiles (%)	Ash (%)	Moisture (%)	Heat* (Btu/lb)	Volatiles (%)	Ash (%)
7-30-68	11.5	4,540	46.2	53.8	1.15	503	4.5	95.5
7-31-68	7.2	8,782	95.2	4.8	0.03	138	4.6	95.4
8- 1-68	23.0	7,696	74.3	25.7	0.22	276	2.0	98.0
Average	13.9	7,006	71.9	28.1	0.47	306	3.7	96.3

*Because of the low heat content, all fines were ignited using benzoic acid as a combustion aid.

Volatile and Ash Contents. Because the volatile and ash fractions are determined in the laboratory on a dry basis, the composition of the residue samples (Text Table 5) must be converted to a dry basis by the following procedure:

$$\text{Percent dry component} = \left(\frac{\text{weight of wet component minus the weight of water in component}}{\text{dry weight of total sample}}\right) 100$$

For example

$$\text{Percent dry unburned combustibles} = \left(\frac{1.7-0.2}{80.6}\right) 100 = 1.9$$

These calculations are summarized in Table B-2.

TABLE B-2

CALCULATION OF PERCENT OF DRY COMPONENT: RESIDUE

Component	Component weight (wet) (lb)	Weight of moisture as sampled		Component weight (dry)	
		%	lb	lb	%
Unburned combustibles	1.7	11.5	0.2	1.5	1.9
Fines	24.8	1.2	0.3	24.5	30.4
Glass and rocks	38.3	0.0	0.0	38.3	47.5
Metal	16.3	0.0	0.0	16.3	20.2
Total sample	81.1	0.6	0.5	80.6	100.0

The volatile content and ash content of the total sample are calculated as follows:

$$\text{Percent volatiles in total sample} = \left[\left(\frac{\text{lb volatiles}}{\text{lb dry unburned combustibles}}\right)\left(\frac{\text{lb dry unburned combustibles}}{\text{lb residue}}\right) + \left(\frac{\text{lb volatiles}}{\text{lb dry fines}}\right)\left(\frac{\text{lb dry fines}}{\text{lb residue}}\right)\right] 100$$

Percent volatiles in total sample = $\left[(0.462)\ (0.019) + (0.045)\ (0.304)\right]\ 100 = 2.2$

Percent ash in total sample = 100 minus the percent volatiles in total sample

Percent ash in total sample = $100 - 2.2 = 97.8$

Heat Content. The laboratory determined the heat content on a dry basis for the unburned combustibles and fines portions of the residue samples. Therefore, the moisture content and noncombustibles present in the total sample must be accounted for when calculating the heat content of tne total sample on an as-sampled basis. The heat content of the total sample is calculated as follows:

$$\text{Heat content in total sample} = \left(\frac{\text{Btu}}{\text{lb dry unburned combustibles}}\right)\left(\frac{\text{lb dry unburned combustibles}}{\text{lb residue}}\right) + \left(\frac{\text{Btu}}{\text{lb dry fines}}\right)\left(\frac{\text{lb dry fines}}{\text{lb residue}}\right)$$

Heat content in total sample = $(4,540)\ (0.019) + (503)\ (0.304) = 239$ Btu/lb residue

APPENDIX C

Calculation of Air Pollution Control Equipment Efficiencies

The efficiency of the air pollution control equipment can be calculated from the results of the simultaneous stack tests at the inlet to and outlet from the equipment. Using the data from the stack tests (Text Table 1), the collector efficiency is calculated in the following manner:

$$\text{Efficiency} = \left(\frac{\text{inlet concentration minus the outlet concentration}}{\text{inlet concentration}}\right) 100$$

Using the data from stack test No. 2 and the particulate emissions expressed in lb/hr, the efficiency of the lower duct spray and scrubber combination is calculated as follows:

$$\text{Efficiency} = \left(\frac{8.70 - 2.78}{8.70}\right) 100 = 68.1 \text{ percent}$$

The remainder of the efficiencies shown in Text Table 4 were calculated in a like manner.

APPENDIX D

Calculation of Combustion Efficiency

These calculations show the methods used to calculate the percent of weight reduction, the percent of volatile reduction, and the percent of heat released. In general, the efficiency of a device can be calculated by:

$$\text{Efficiency} = \frac{\text{quantity in minus quantity out}}{\text{quantity in}}$$

Weight Reduction Efficiency. Specifically, the weight reduction efficiency is calculated as follows:

$$\text{Percent dry weight reduction} = \Bigg(\Bigg\{\Big[\Big(\Sigma \text{ wt waste charged per day}\Big)\Big(1 - \text{moisture content of waste for that day}\Big)\Big] - \Big[\Big(\Sigma \text{ wt of residue}\Big)\Big(1 - \text{moisture content of residue}\Big) + \Big(\text{wt of particulates emitted to atmosphere}\Big) + \Big(\text{wt of solids in wastewater*}\Big)\Big]\Bigg\} 100\Bigg) \div \Big[\Big(\Sigma \text{ wt waste charged per day}\Big)\Big(1 - \text{moisture content of waste for that day}\Big)\Big]$$

However, the weight of particulates emitted to the atmosphere plus the weight of solids in the wastewater equal the weight of particulates

*Not measured.

at the inlet to the air pollution control system. The determination of the various items for this calculation is as follows:

$$\text{Weight of dry component} = \text{weight wet component} \left[1 - \left(\frac{\text{percent moisture content}}{100}\right)\right]$$

For example

$$\text{Weight of dry solid waste (7-30-68)} = (9{,}040) \left[1 - \left(\frac{27.4}{100}\right)\right] = 6{,}560$$

These calculations are summarized in Table D-1.

TABLE D-1

CALCULATION OF DRY COMPONENT WEIGHT

Component and date collected	Component weight (wet) (lb)	Moisture content (%)	Component weight (dry) (lb)
Solid waste:			
7-30-68	9,040	27.4	6,560
7-31-68	10,200	32.2	6,910
8- 1-68	7,250	24.8	5,450
Total	26,490	---	18,920
Residue:			
7-30-68	2,000	0.59	1,990
7-31-68	2,450	0.06	2,450
8- 1-68	2,400	0.38	2,390
Total	6,850	---	6,830

The particulate emissions at the inlet to the air pollution control system are determined as follows:

$$\text{Weight of particulate emissions per day} = \text{Weight of particulate emissions per ton of waste} \times \text{Weight of waste charged per day}$$

$$\text{Weight of particulate emissions (7-30-68)} = (10.6)\ (4.52) = 47.9 \text{ lb/day}$$

These calculations are summarized in Table D-2.

TABLE D-2

CALCULATION OF DAILY PARTICULATE EMISSIONS

Date	Particulate emissions (lb/ton waste)	Waste charged (ton/day)	Particulate emissions (lb/day)
7-30-68	10.6	4.52	47.9
7-31-68	18.2	5.10	92.8
8- 1-68	30.4	3.63	110.3
Total	---	---	251.0

The weight of reduction efficiency is determined as follows:

$$\text{Percent dry weight reduction} = \left\{\left[18{,}920 - (6{,}830 + 250)\right] \quad 100\right\} \div 18{,}920$$

$$\text{Percent dry weight reduction} = 62.5$$

Volatile Reduction Efficiency. The reduction in volatile content is calculated by the following equation:

$$\text{Percent volatile reduction} = \left\{\left[\text{wt of volatiles in waste} - \left(\text{wt of volatiles in residue} + \text{wt of volatiles in particulates emitted to atmosphere*} + \text{wt of volatiles in wastewater solids*}\right)\right] 100\right\} : \text{wt of volatiles in waste}$$

The determination of the various items for this calculation is as follows:

$$\text{Weight of dry volatiles} = \left(\text{Weight of dry component}\right)\left(\text{Percent of dry volatiles}\right) : 100$$

Weight of dry volatiles in solid waste (7-30-68) = (6,560) (57.2) : 100 = 3,750

These calculations are summarized in Table D-3.

The volatile reduction efficiency is determined as follows:

$$\text{Percent volatile reduction} = (10{,}500 - 135.8)\ (100) : 10{,}500$$

$$\text{Percent volatile reduction} = 98.6$$

Heat Reduction Efficiency. The efficiency of heat release is determined as follows:

$$\text{Percent heat released} = \left\{\left[\text{heat content in solid waste} - \left(\text{heat content in residue} + \text{heat content in particulates emitted to atmosphere*} + \text{heat content in solids in wastewater*}\right)\right] 100\right\} : \text{heat content in solid waste}$$

*Not measured.

TABLE D-3

CALCULATION OF WEIGHT OF DRY VOLATILES

Component and date collected	Component weight (lb)	Volatiles	
		%	lb
Solid waste:			
7-30-68	6,560	57.2	3,750
7-31-68	6,910	57.5	3,980
8- 1-68	5,450	50.8	2,770
Total	18,920	---	10,500
Residue:			
7-30-68	1,990	2.2	43.8
7-31-68	2,450	2.1	51.4
8- 1-68	2,390	1.7	40.6
Total	6,830	---	135.8

Determination of the various items for this calculation is as follows:

Heat content = Btu/lb × weight of component

For example

Heat content of solid waste = (3,890) (9,040) = 35.2×10^6 Btu

These calculations are summarized in Table D-4.

TABLE D-4

CALCULATION OF TOTAL HEAT CONTENT

Component and date collected	Component weight (lb, as sampled)	Heat content	
		Btu/lb, as sampled	Total Btu
Solid waste:			
7-30-68	9,040	3,890	35.2×10^6
7-31-68	10,200	3,620	35.9×10^6
8 -1-68	7,250	4,020	29.2×10^6
Total	26,490	---	100.3×10^6
Residue:			
7-30-68	2,000	239	47.8×10^4
7-31-68	2,450	97	23.8×10^4
8- 1-68	2,400	217	52.1×10^4
Total	6,850	---	123.7×10^4

The heat reduction efficiency is determined as follows:

$$\text{Percent heat released} = \frac{\left[(100.3 \times 10^6) - (1.2 \times 10^6)\right] \quad 100}{100.3 \times 10^6}$$

Percent heat released = 98.8